

**DOE Bioenergy Technologies Office (BETO)**

**2023 Project Peer Review**

**Scale up of Novel Drying and Extraction Unit Operations**

**April 4, 2023**

**Systems Development and Integration Session B**

**David Hazlebeck**

**Global Algae Innovations**

# Global Algae Innovations

## *Algae Solutions to Global Dilemmas*

### Vision

Harness the unparalleled productivity of algae to provide food and fuel for the world, dramatically improving the environment, economy, and quality of life for all people

- Founded Dec 2013
- Algae for commodities
- Technology development in 8-acre Kauai Algae Farm
- Radical advances throughout the entire process
- Selected as XPRIZE Carbon Removal milestone award winner in 2022
- Scaling-up suite of novel technologies in new San Luis Obispo County Farm

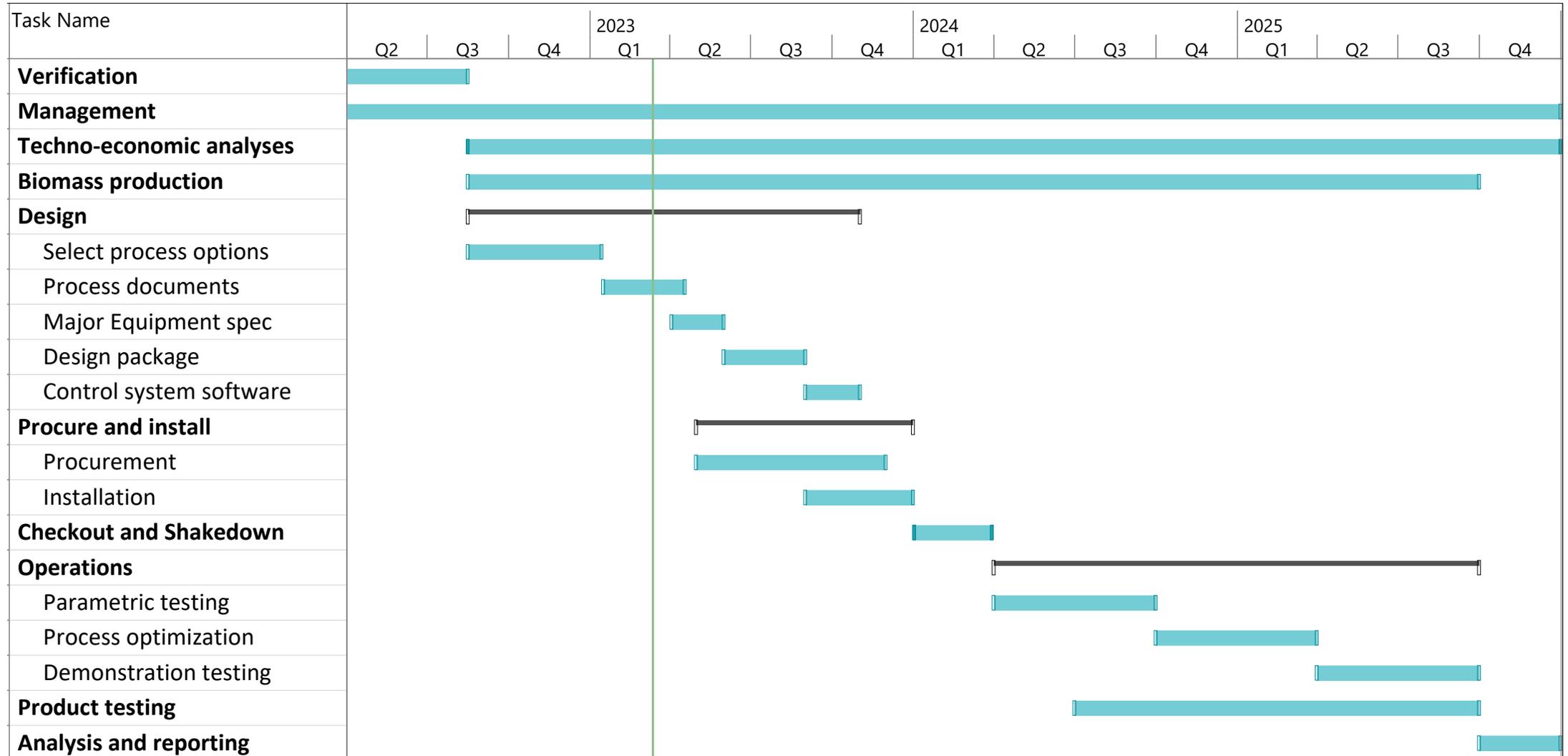
# Project Overview – Goals

- **Scale-up drying and extraction unit operations**
  - Drying and extraction operations at 20 kg/hr throughput
  - Operate for at least 500 hours and 100 hours continuously
  - Drying energy of less than 2MJ/kg algae
  - Extraction efficiency of at least 85% with energy use less than 0.2 MJ/kg algae
  - Test and validate product value for fuel, polymers, and aquaculture feed
- **Unit operations support an integrated algae biofuel process that achieves**
  - An 80% reduction in greenhouse gas emissions relative to petroleum fuel
  - A minimum fuel selling price of \$2.50 per gallon of gasoline equivalent
  - Based on techno-economic analysis (TEA) for 5,000 cultivation acre algae farm

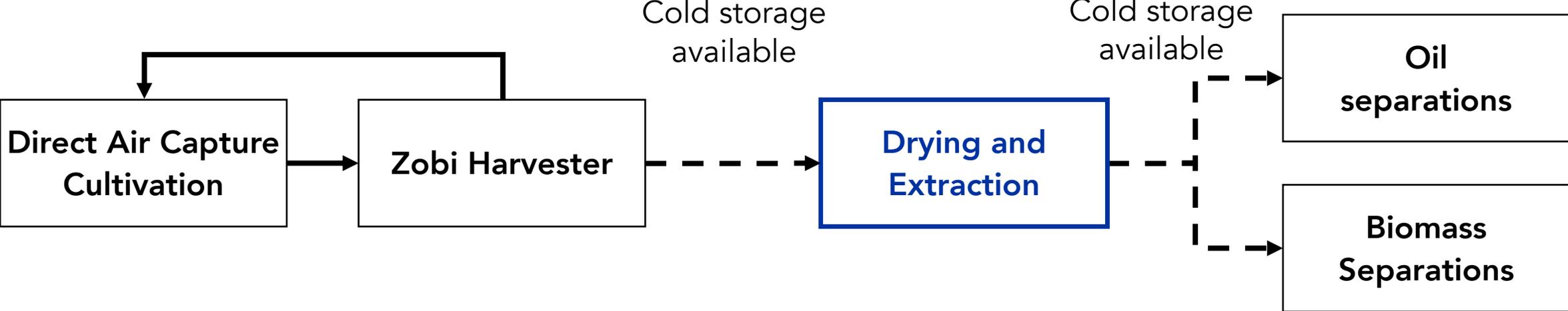
# Project Overview – Context and History

- **Developed 25 novel unit operations at laboratory-scale for downstream processing under an on-going BETO project**
  - Lower energy use and cost
  - Increase value of the product spectrum
  - Generate recycle streams
- **Many flow sheet options for an algae biorefinery using various combinations and orders of the unit operations**
- **The other on-going project continues to generate new data evaluating various options and product qualities**

# Project Overview - Schedule



# Approach – Overall Algae Process



Leverage  
Concurrent scale-up project

**This Project**

Leverage  
Lab-scale projects and vendor demonstration equipment

# Approach – Project Tasks

## Update TEA throughout to support decision making and key performance parameters

1. Down-select to a flow sheet for scale-up based on TEA incorporating latest cost information and process flow sheets that are supported by laboratory-scale results
2. Evaluate equipment design options and prepare on equipment specifications
3. Procure and install system at the new algae farm in San Luis Obispo County
  - a. Integrated with cutting edge cultivation and harvesting technology
4. Checkout and shakedown
5. Parametric testing
6. Optimization based on cost that meets LCA requirements using TEA
7. Test variability, establish quality control points, produce product samples
8. Product samples to sub-recipients for testing
  - a. Jet and diesel fuel - Neste
  - b. Polymers – Algenosis
  - c. Aquaculture feed -Hubb’s SeaWorld Research Institute, Zeigler, and USDA ARS

# Approach – Challenges and Milestones

- **Key Technical Challenges**
  - Achieving exceptional energy, cost, and efficiency goals
  - Integrating five novel unit operations
  - Maintaining separation efficiencies in larger-scale equipment
- **Design, install, procure**
  - TEA/LCA metrics for energy, life-cycle, minimum selling price
  - Mostly completion milestones
- **Operational metrics**
  - Define key performance parameters during design and measure in parametric testing
  - Overall project goals for energy use, cost ,efficiency achieved during optimization
  - Longer-term operation and samples from optimized process
  - Fuel and polymers from samples meet product specifications
  - Aquaculture feed apparent digestibility coefficients comparable to fishmeal

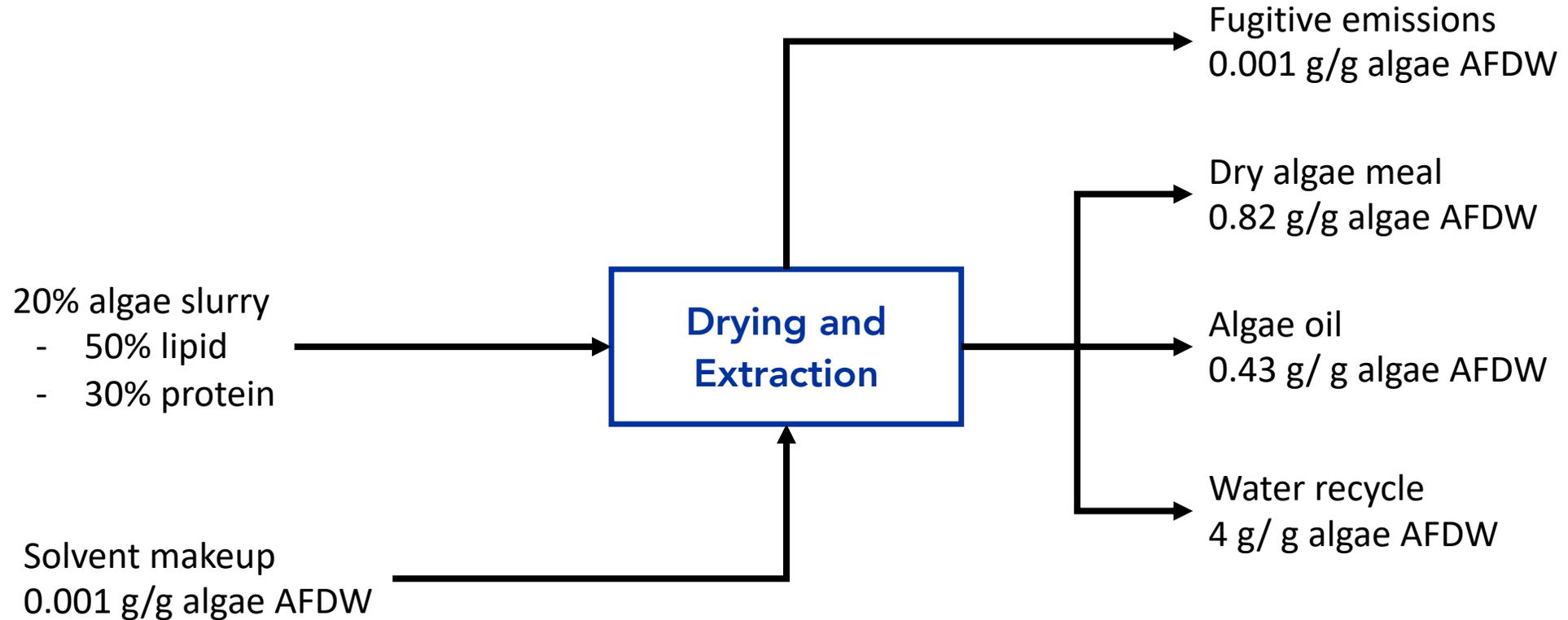
# Approach – Challenges & Risks

Risk	Mitigation
Missing key laboratory-scale observations	Utilize same engineers/scientists from lab-scale project in this scale-up
Long delivery times delay project	Early procurement of long-lead items Plan for late drop in of some equipment Modify equipment designs to utilize used or more available equipment
Cost increases from inflation	Make use of same equipment in multiple steps Utilize surplus or used equipment where practical and available
Separations operations fail	Equipment specification includes evaluation of alternative separations Maintain list of secondary options Extra budget for checkout/shakedown Chemical engineers with extensive checkout/shakedown/start-up experience
Meeting exceptional goals	Parametric testing to understand effects of process variables TEA driven optimization based on parametric tests
Algae biomass availability	Co-located with cultivation scale-up Refrigerated storage to match rates and timing

# Progress and Outcomes - Overview

- **Project in recently started, currently in equipment specification phase**
- **Verification results**
  - Used 49% lipid content algae cultivated at the Kauai Algae Farm
  - Novel drying process – less than 7% moisture content
  - Novel extraction process - 99.1% lipid extraction efficiency
- **Flow sheet down-selected for scale-up**
  - Mass and energy balances (M&EB) integrated into techno-economic analysis (TEA)
  - TEA updated to 2022 dollars and results from 160-acre design project incorporated
  - Selection flow sheet had lowest cost and best life-cycle analysis (LCA)
  - Includes 5 patentable unit operations in drying and extraction
- **Product spectrum**
  - Doubles the revenue from algae biomass
  - Commensurate with 7 billion gallons of fuel per year and 4 million acres of algae

# Progress and Outcomes – M&EB Summary



Extraction energy (0.3 MJ/kg algae)  
- Heat 0.23  
- Electricity 0.07

Drying energy (1.37 MJ/kg algae)  
- Heat 0.60  
- Electricity 0.77

# Progress and Outcomes

## Original

Market	Fraction (% AFDW)	Selling Price (\$/mt)	Composite (\$/mt)
Biofuel	50%	825	410
Protein meal	50%	570	290
<b>Total</b>	<b>100%</b>		<b>700</b>

## New

Market	Fraction (% AFDW)	Selling Price (\$/mt)	Composite (\$/mt)
Biofuel	17%	825	140
Polymer	17%	2300	390
Omega-3 feed	6%	4200	250
Glycerin	5%	1100	60
Protein Conc.	12%	1800	220
Aquafeed meal	43%	800	340
<b>Total</b>	<b>100%</b>		<b>1400</b>

# Impact

- Engineering-scale data on novel drying and extraction process
  - Lower energy and improved economics relative to current BETO baselines
- Produce biomass to develop algae product markets and off-takes
  - Project partners: Neste, Algenesis, Zeigler
  - Planning for many more when sample products are available
- Product spectrum with higher value and markets commensurate with 7 billion gallons of fuel per year
- Large risk reduction in moving integrated algae process to pilot-scale
- Planning to submit 26 patent applications this year on drying and extraction technologies

# Summary

- **Accelerate commercialization**

- Demonstrate novel low energy, low cost drying and extraction at engineering-scale
- 100% increase in biomass value for product spectrum commensurate with 7 billion gallons of algae biofuel per year
- Product samples will enable development of markets and off-takes

- **Partnerships with off-takers**

- Multiple partners on the team
- Tons of material will be available to expand markets and off-takes

- **Status**

- Process down-select complete, meets TEA/LCA goals
- Starting equipment selection and specification

# QUAD Chart Overview

## Timeline

- BP2 start date: August 2022
- Project end date: December 2025

	FY22 Costed	Total Award
DOE Funding	\$91,000	\$4,000,000
Project Cost Share	\$23,000	\$1,000,000

TRL at Project Start: 4  
TRL at Project End: 5

## Project Goal

Scale up a novel drying and extraction process from laboratory to engineering scale (20 kg/hr); optimize the process to achieve challenging energy, cost, and life-cycle targets; produce product samples; and test the product samples for fuel, polymer, and aquafeed.

## End of Project Milestones

- 500 hours of operation, 100 hours continuous
- 85% extraction efficiency
- 2 MJ/kg drying and 0.2 MJ/kg extraction
- \$2.50/GGE and 80% GHG reduction

## Funding Mechanism

FY20 Multi-Topic FOA - SCUBA

## Project Partners:

- TSD (engineering)
- Zeigler (aquafeed)
- Neste (fuel)
- Hubbs SeaWorld RI (aquafeed)
- Algenesis (polymer)

## Additional Slides

# Responses to Previous Reviewers' Comments

- **Not previously reviewed**
- **Go/No-Go Review**
  - Verification test December 2021
  - Feed ~1 liter of algae slurry: 8.4% total solids, 5.7% AFDW algae, 28g oil
  - Extraction efficiency 99%: 27.8g oil
  - Water removal 93%

# Publications, Patents, Presentations, Awards, and Commercialization

- None to date